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Ultrasound thermometry for optimizing heat supply during a hyperthermia therapy of cancer tissue

Mario Wolf*, Katharina Rath, Andrés Eduardo Ramos Ruiz, Elfgard Kühnicke

TU Dresden, Solid state electronics laboratories, Helmholtzstraße 18, 01069 Dresden, Germany

Abstract

Monitoring the temperature during a hyperthermia therapy allows optimizing the heat supply to destroy the cancer whereby the damage in the surrounding tissue is minimized. This contribution presents the fundamental research and current work to realize a locally resolved, noninvasive and intra-surgically applicable temperature measurement in tissue. This is realized by measuring the sound velocity locally resolved by an annular array, which allows noninvasive measurements although the observed tissue is not accessible from all directions. The method had been already qualified for fluids and analyses the echoes of moving scattering particles to obtain the time of flight to the focus of the transducer. As the parameters of the transducer are known the focus position (and thus the time of flight) can be calculated as a function of the sound velocity distribution of the propagation medium. Hence the measured time of flight allows determining the focus position and mean sound velocity simultaneously by means of this function. Varying the time lags of the signals for each element allows moving the focus and so measuring locally resolved. This contribution presents first ex-vivo measurements in tissue and thus proves the adaptability of this technique for tissue.

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1. Introduction

Local hyperthermia therapy allows a thermal destruction of cancer tissue. As it works noninvasively, the surrounding tissue is damaged minimally [1]. The whole tumour has to be heated to a temperature of 45 °C [2,3]. If there are big vessels near the tumour, they cause a heat transfer and the critical temperature is not reached in the whole tumour. Therefore a temperature monitoring is necessary. A temperature monitoring in human body is possible

* Corresponding author. Tel.: +49-351-463-43783; fax: +49-351-463-32320.

E-mail address: mario.wolf@tu-dresden.de

using MRI. But a simultaneous application of hyperthermia- and MRI-device is still an objective of current research [4]. Actually, the tumour is examined by imaging techniques after the surgery, which has to be repeated, if the cancer tissue has not been destructed completely. A temperature monitoring with ultrasound could be applied during the therapy and would be much more cost efficient.

Current works [5,6,7] propose to monitor the temperature by echo tracking techniques: A change of temperature causes a change in the speed of sound and an expansion of the tissue. This causes a change in the time of flight to a reflector. These time shifts are determined by cross-correlation of the recorded signals using characteristic echo parts. If the dependence of speed of sound and expansion from temperature are known, the change of temperature can be determined from the time shifts. But this proposal does not take into account the individual properties of the tissue. Furthermore, it fails if there is a deformation of the tissue, caused by heating or even by the heart beat, or if denaturation starts.

This contribution proposes a novel approach to determine the position of a reflector and the average sound velocity between transducer and reflector simultaneously. It works by varying the focussing mode of an annular array as described in section 2. The method is applied ex-vivo on pork liver and some results, which prove the feasibility of the technique are presented in section 3. Section 4 discusses the occurring challenges and gives a short conclusion.

2. Approach

A half-analytical method has been developed to optimize transducers and to calculate the sound field in complex structures and layered media. It is based on time-harmonic GREEN's functions in a steepest descent approximation for a two-dimensional geometry [8]. For this reason, the source area is discretized and uniformly covered with point sources. The sound field that is irradiated from a finitely extended source is the superposition of the field of all point sources. This method is applied here to simulate the fields of the single elements of the annular-array which is used for the measurements. An annular array of four elements with a centre frequency of 3 MHz and a spherical curvature of 70 mm is used in this contribution. Figure 1 shows the structure and the sound fields of the elements.

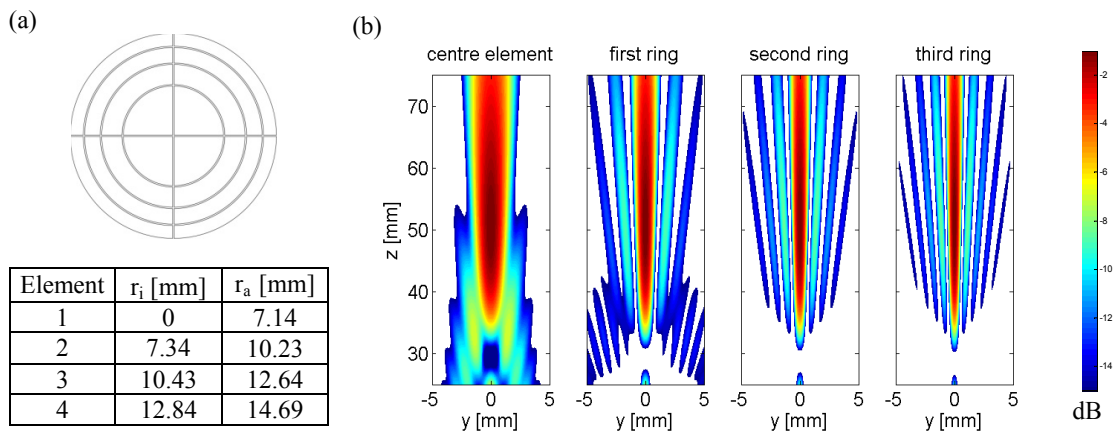


Fig.1: (a) structure and dimensions of used array; (b) calculated sound fields of the used annular array

Focussing works by a superposition of measured signals where each is delayed with a calculated time: The sound paths from each element to the designed focus point z_{Fok} are determined. With an assumed sound velocity of the propagation medium these paths allow to calculate the differences in time of flight, which are used as delay times for each element so that all waves arrive at the focus point at the same time. Of course if e.g. the temperature in the medium changes this causes a change of sound velocity. The focus moves because the positive interference arises at another point (Fig. 2). As calculated sound fields are in the Fourier transformed domain also the delay times have to

be transformed into phase shifts. A superposition of the phase shifted sound fields generates the focus at the designed point.

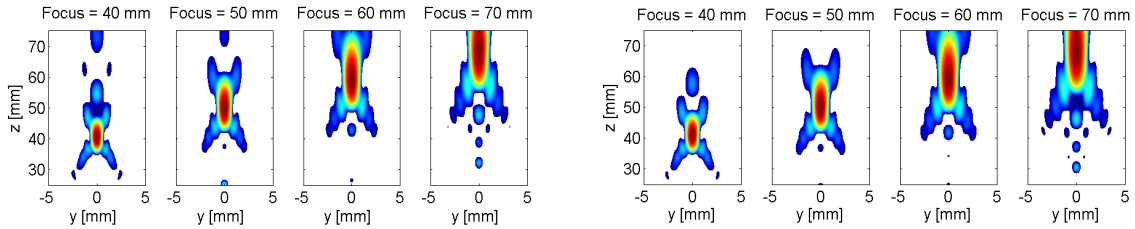


Fig. 2: calculated, focussed sound fields in different media – left: $c_{Med} = 1500$ m/s, right: $c_{Med} = 1650$ m/s; focussing with a control sound velocity $c_{Fok} = 1500$ m/s at designed focus points from 40 to 70 mm db skala

Because the amplitude of the echo of a pointlike reflector is proportional on the sound pressure at its position, it also depends on the used set of delay times (control mode). It becomes maximal if focus and reflector position coincide. Thus the dependence of control mode and echo amplitude can be used as an additional measure beside the time of flight.

3. Measurements

Measurements are done with the previously presented array on pork liver embedded in saline solution. A time window is moved stepwise along the signal to realize a locally resolved measurement (black lines) and the signal section in this window is analyzed. Figure 3 shows exemplarily an already focused signal.

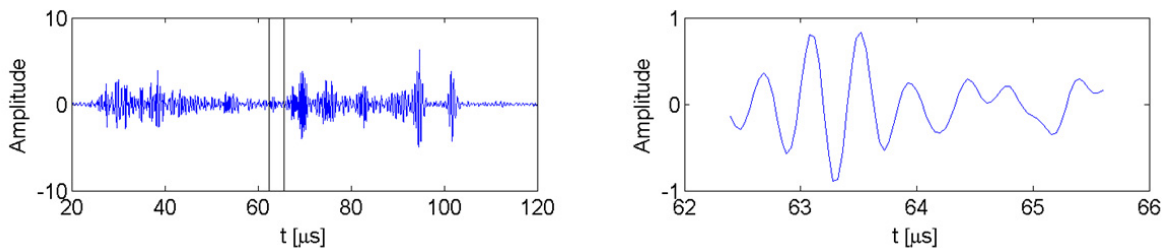


Fig. 3: focussed echo with a control mode of $c = 1590$ m/s and a designed focus position of 50.6 mm: (a) whole recorded signal, (b) signal in analyzed time window ($t_{Start} = 62.4$ μ s; $t_{End} = 65.6$ μ s)

The designed focus position is varied for the assumed control sound velocity c_{Fok} and the maximal amplitude of the echo is determined in dependance of z_{Fok} (Fig 4.a). The maximum of this curve gives the supposed reflector position z_{Max} . Although there is a big global maximum, the maximum has to be found in the defined time window. By varying the control sound velocity the position z_{Max} can be determined as a function of c_{Fok} (Figure 4b, blue line). Additional information gives the time of flight of the echo in the time window (Figure 4b, black line). The correct sound velocity and reflector position can be determined from the intersection of these curves. Temperatures has been increased by steps of 3 K from $T = 19$ °C to 40 °C. The sound velocity raised from 1590 m/s to 1610 m/s.

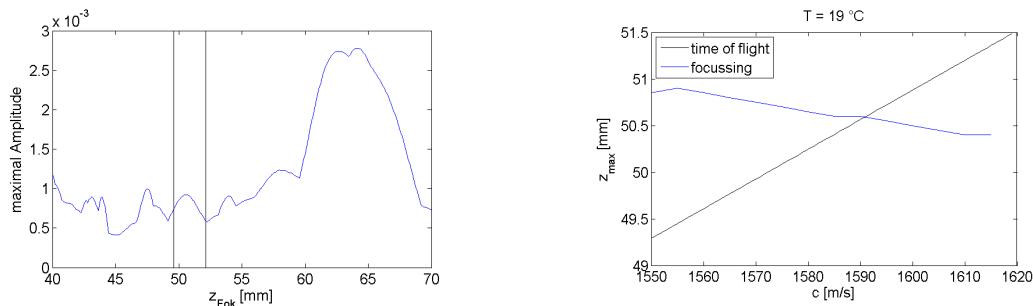


Fig. 4: (a) signal amplitude as a function of designed focus point for $c_{\text{Fok}} = 1590$ m/s (b) maxima of focussing curves as a function of control sound velocity (blue line) and reflector distance as a function of sound velocity, determined from time of flight (black line)

4. Discussion and Conclusion

The presented approach currently works only for small reflectors (see time window Fig 3). The reason is that only pointlike reflectors cause an echo proportional to the sound pressure. The echo parts with high amplitudes are due to large, extended reflectors. The amplitude of their reflected signals depends not only on their position but also on their geometry. Knowledge from previous research can be applied to analyze these echos. So it should be possible to distinguish between plane and curved reflectors [9]. For plane reflectors [10] can be applied and [11] for curved. Also the experimental setup has to be improved. The tissue may not be older than 6 hours to avoid a change of acoustic properties. Also reference measurements on tissue phantoms are being planned.

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